# Modeling Hopping Transport in Three-Dimensional Systems Using Au Nanoparticle Clusters: New Challenges in Nanoelectronics

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Self-assembled Au nanoparticle clusters can be viewed as a new model system to study hopping transport in two and three dimensions. The physics of such systems is governed by two parameters, charging energy and tunnel coupling between the particles. The nanoparticles that we use are sufficiently small, such that Coulomb blockade effects play an important role in electrical transport even at room temperature. In this model system, the magnitude of the tunnel coupling.between the islands is determined by the thiol-coating used. To get a wide range of tunnel couplings, we have synthesized gold nanoparticles with various thiol coatings, including 1-octanethiol, 1-dodecanethiol, 4-mercaptodiphenylacetylene, 4-nitro-4'-mercaptodiphenylacetylene, and 3,5-dinitro-4'-mercaptodiphenylacetylene. For electrical studies we fabricated interdigitated electrodes with electrode spacings down to 100 nm. The gold nanoparticle films were deposited on the electrodes with an airbrush technique. I-V characteristics were measured from room temperature down to 1.5 K. Low bias resistance was found to be activated with an activation energy of 40-60 meV, consistent with what is expected based on the size of the nanoparticles. The devices exhibit Middleton-Wingreen type universal I-V behavior, $I \propto (V - V_{th})^{\zeta}$, at low temperatures with a scaling exponent of $\zeta \approx 3$. The Coulomb gap extracted from such scaling fits is found to scale linearly with the electrode spacing. The size of the Coulomb gap is found to be significantly larger in gold nanoparticle clusters where the thiol coating has weak tunnel coupling. This was unexpected as the Coulomb gap for an array of metal islands should only depend on the size of the nanoparticles. We explain this discrepancy by assuming a wide variation in tunnel couplings, which would lead to highly meandering paths for current flow. The relevance of this finding to other hopping systems will be discussed.